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INFLUENCE OF SOIL FROST ON INFILTRATION OF SHRUB COPPICE DUNE AND DUNE INTERSPACE SOILS IN SOUTHEASTERN NEVADA

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Abstract.—The influence of soil frost on the infiltration rate of shrub coppice dune and dune interspace soils was evaluated near Crystal Springs, Nevada, using simulated rainfall. The infiltration rate of the coppice dune soil was greater than the dune interspace soil under frozen or unfrozen conditions. Because of different vegetation cover and surface soil characteristics, coppice dune and dune interspace soils responded differently to freezing, thus imposing a spatial and temporal response to infiltration rate. Infiltration rate of soils with porous concrete frost increased as the soils thawed during simulated rainfall, but soils with nonporous concrete frost allowed very little infiltration to occur. Both coppice dune and dune interspace soils that were classified in January as having granular frost had a higher infiltration rate than the same unfrozen soils in March.

Soil frost influences water infiltration rates and is often a major influence on runoff (Gray and Granger 1987, Harris 1972, Haupt 1967, Kane and Stein 1983, Klock 1972, Kuzick and Bezmenov 1963, Wilcox et al. 1989, and Zuzel and Pikul 1987). Areas where soil frost strongly influences infiltration are characterized by cold winters, transient snow cover, and soils that may freeze and thaw several times each winter, in addition to a diurnal freeze-thaw cycle (Pikul and Allmaras 1986, Zuzel et al. 1986). Infiltration rate of frozen soil is strongly influenced by the structure of the soil frost, which is determined in part by the soil water content at the time of freezing. Concrete frost has been identified as having the greatest impact on infiltration rates (Haupt 1967, Lee and Molnau 1982, Story 1955).

The spatial influence of shrub coppice dune and dune interspace soils on infiltration of unfrozen soil was originally established by Blackburn (1975) and verified by numerous other investigators (Johnson and Gordon 1988, Swanson and Buckhouse 1984, Thurow et al. 1986, Wood and Blackburn 1981, Wood et al. 1987). Because shrub coppice dune and dune interspace soils have different vegetation cover and surface soil characteristics, we hypothesized that they will respond differently to soil freezing and thawing, thus imposing a spatial and temporal response to infiltration during winter. The study objective was to determine the spatial variation in infiltration rates of frozen and unfrozen shrub coppice dune and dune interspace soils.

Study Area

The study area is located in southeastern Nevada about 7 km west of Crystal Springs, 37°20′ N latitude, 115°20′ W longitude at 1,200 m elevation, and 9 km east of the 1,850–2,100 m ridgeline of the Pahranagat Range. The normal annual precipitation of 330 mm occurs mostly during winter as snow or during July and August as thundershowers. Winters are characterized by periodically cold temperatures with frequent diurnal freeze-thaw cycles.

Blackbrush (*Coleogyne ramosissimum*) is the dominant shrub, with 22% crown cover; associated species are joint fir (*Ephedra nevadensis*) and box thorn (*Lycium andersonii*), each with 2% crown cover. Herbaceous cover is sparse. The study site is located on the tops of long, narrow alluvial fans with 5% slope to the east, and the soils are loamy-skeletal, mixed, thermic, shallow, Typic Durorthids.

Two major types of surface soils are found on the study site: the coppice dune soil under shrubs and the barren interspace soil between shrubs. The coppice dune soil covers 35% of

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the surface, whereas interspace soil covers 65%. The A horizon of the coppice soil is characterized by a weakly subangular blocky structure and a gravelly sandy loam texture. Interspace soils have gravel pavement several pebbles thick over the mineral soil. The 50-mm-thick, loamy, crusted A horizon is massive, has vesicular pores, and is broken into 80–150-mm-diameter polygons. The crusted interspace soil slakes and disperses readily when wetted.

Methods

Infiltration rates were determined using a drip-type rainfall simulator (Blackburn et al. 1974) with simulated raindrops 2.5 mm in diameter. Drops falling 2.1 m reach 5.25 m sec^{-1} or 71% of the terminal velocity achieved by raindrops in an unlimited fall (Laws 1941). Simulated rainfall was applied on frozen soil in January and on unfrozen soil in March 1974 at a rate of 76 mm hr^{-1} for 30 min. The rainfall intensity was chosen to assure runoff from each study plot. Runoff plots (280 × 500 mm) were randomly placed on 16 and 6 shrub coppice dune soils and 13 and 5 interspace soils during the January and March sample dates, respectively. This sample size is considered adequate for rangeland conditions (Wood 1987). Shrubs were cut at ground level and removed from the coppice dunes to reduce rainfall interception losses.

Volume of runoff was measured every 5 min for 30 min. Infiltration rates were determined as the difference between simulated rainfall and runoff volumes. Soil frost was characterized adjacent to each runoff plot prior to the simulated rainfall event. Three structural forms of soil frost were observed and subjectively classified according to criteria by Hale (1951) and Haupt (1967). Granular frost consisted of scattered granules of ice binding mineral soil together. Nonporous concrete frost was characterized by dense, thin ice lenses and ice crystals. Porous concrete frost was less dense than concrete frost, but frozen chunks of soil were harder to break. Porous concrete frost was further defined by resistance to repeated thrusts of a pick before being punctured. Water used for rainfall simulation averaged 4 C in January and 9 C in March. Analysis of variance and least significant difference mean separation tests (Snedecor and Cochran 1971) were used to test for differences between infiltration rates of the coppice dune and dune interspace soils for the January and March sample dates.

Results and Discussion

All plots during January were classified as having soil frost 100 mm thick located about 50 mm below the surface. Three of the coppice dune and five of the interspace plots were classified as granular frost. The remaining plots of both soils were characterized as porous or nonporous concrete frost, of which 12 coppice dune and 6 interspace plots were classified as porous concrete frost.

Infiltration rate after 25 min was significantly greater for coppice dunes than for dune interspaces under both frozen and unfrozen soil conditions (Fig. 1, Table 1). Similar relationships between unfrozen shrub coppice dune and dune interspace soils have been reported by Blackburn (1975), Johnson and Gordon (1988), Thurow et al. (1986), and Wood and Blackburn (1981). The differences in infiltration of coppice dune and dune interspace soils have been attributed to differences in vegetation and surface soil characteristics (Blackburn 1975, Johnson and Gordon 1988). Infiltration of unfrozen rangeland soil is usually characterized by a high initial rate that decreases rapidly with time and stabilizes at some constant rate within 30 to 60 min (Fig. 1). However, mean infiltration rates in January declined within the first 15 min for the coppice dune soils and within 20 min for interspace soils; in neither case did they stabilize at a constant rate. Infiltration rates for both soils increased during the latter part of the rainfall due to thawing of the porous concrete soil frost layer of some plots (Figs. 2, 3). As a result, there was no significant difference in 30-min infiltration rates between frozen and unfrozen dune interspace soils. However, 30-min infiltration rates tended to be lower in the frozen coppice dune soils in January than in unfrozen soils in March (Fig. 1).

Infiltration rates of coppice dune plots classified as granular frost were similar to the rainfall application rate and 10 mm hr^{-1} greater than when the soils were unfrozen in March (Figs. 1, 2). Coppice dune plots classified as porous concrete frost and thawing during the rainfall event reached a minimum

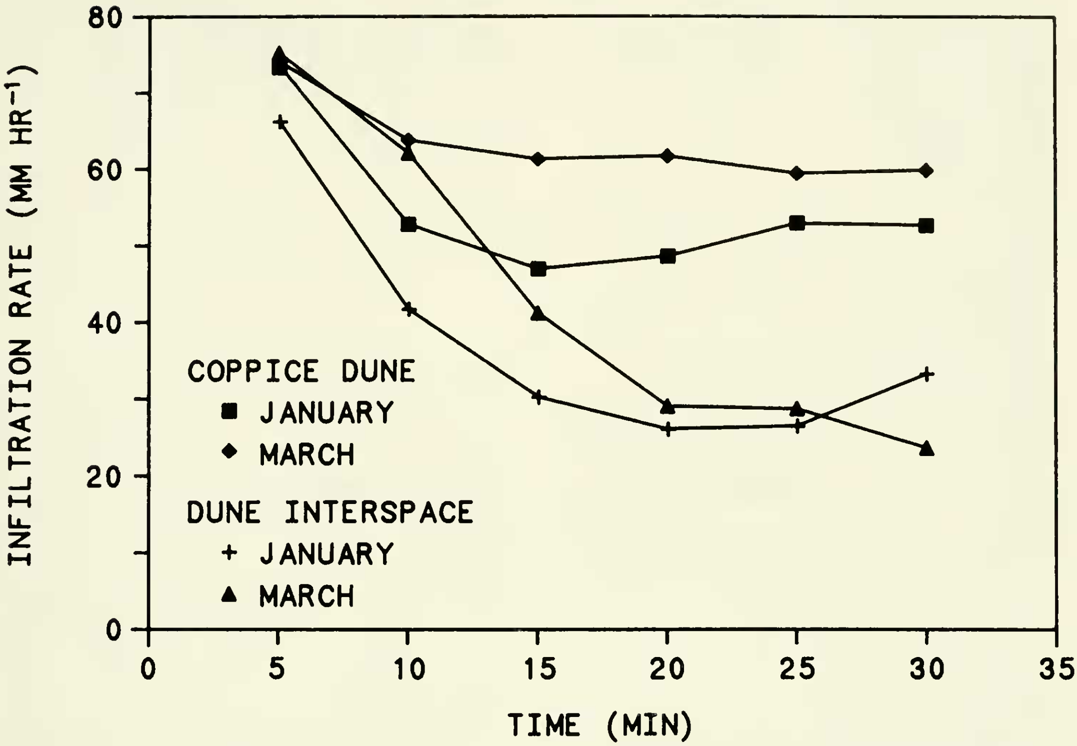

Fig. 1. Mean infiltration rates for all coppice dune and dune interspace soils in January and March, Crystal Springs, Nevada.

TABLE 1.—Significant difference of five-minute interval infiltration rates for coppice dune and dune interspace soils for the January and March sample dates[1], Crystal Springs, Nevada.

Soil/Sample date	Time (minutes)					
	5	10	15	20	25	30
Coppice March vs. coppice January	ns[2]	ns	ns	ns	ns	ns
Coppice March vs. interspace March	ns	ns	ns	*	*	**
Coppice March vs. interspace January	ns	ns	**	**	**	*
Coppice January vs. interspace March	ns	ns	ns	ns	*	**
Coppice January vs. interspace January	ns	ns	ns	**	**	*
Interspace January vs. interspace March	ns	ns	ns	ns	ns	ns

[1]Sample size: coppice, January n = 16, March n = 6; interspace, January n = 13, March n = 5.
[2]Level of significance ($P \leq .01$ = **; $P \leq .05$ = *; ns = nonsignificant at $P > .05$) determined with a one-way analysis of variance and a least significant difference (lsd) mean separation test.

infiltration rate after 20 min of 44 mm hr^{-1}, but 30-min rates increased to a rate similar to that of the granular frost plots (Fig. 2). The one porous concrete frost plot that remained frozen during the rainfall event reached a minimum rate after 15 min and then increased slightly during the remainder of the event to 33 mm hr^{-1}.

Infiltration rate at 30 min of interspace soil with granular frost was 14 mm hr^{-1} greater than when the soil was unfrozen in March. Interspace plots that were initially classified as porous concrete frost and thawing during the rainfall event reached a minimum infiltration rate of 12 mm hr^{-1} after 20 min, after which rates increased and were similar to unfrozen soils in March. Infiltration rate of the interspace nonporous concrete frost plot decreased to 2 mm hr^{-1} at 30 min, 21 mm hr^{-1} lower than the 30-min rate of unfrozen soils in March. Other researchers have reported similar infiltration response caused by soil frost

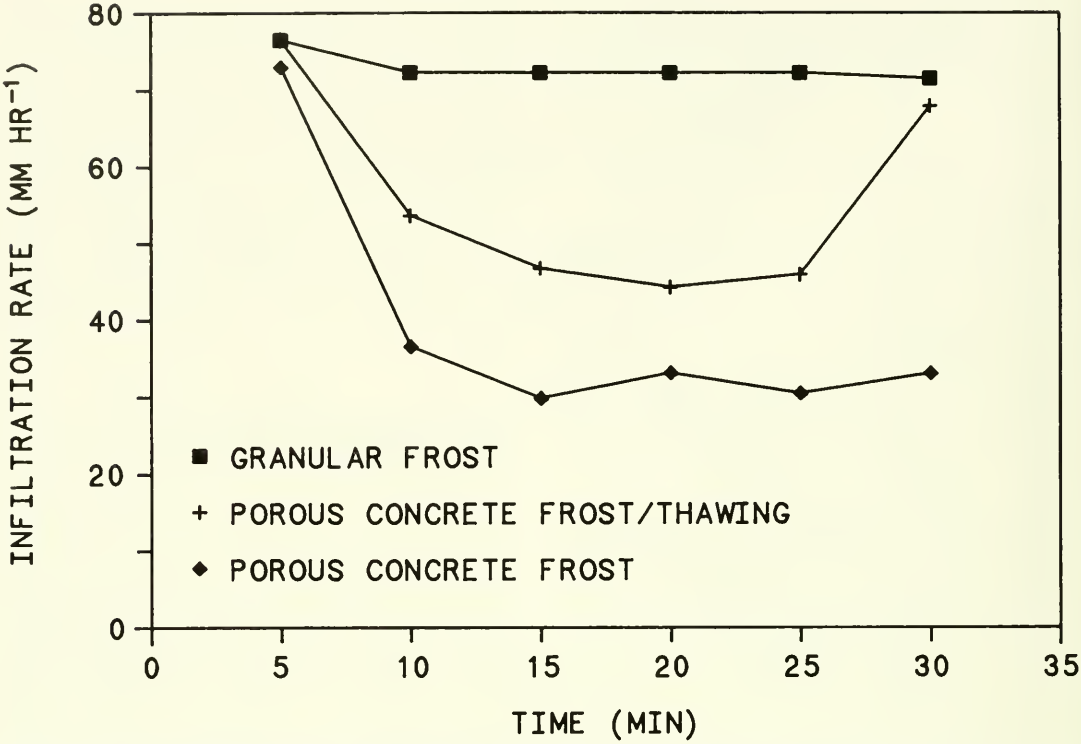

Fig. 2. Infiltration rates in January for coppice dune soils classified as having granular frost, porous concrete frost that was thawing during the rainfall event, and porous concrete frost, Crystal Springs, Nevada.

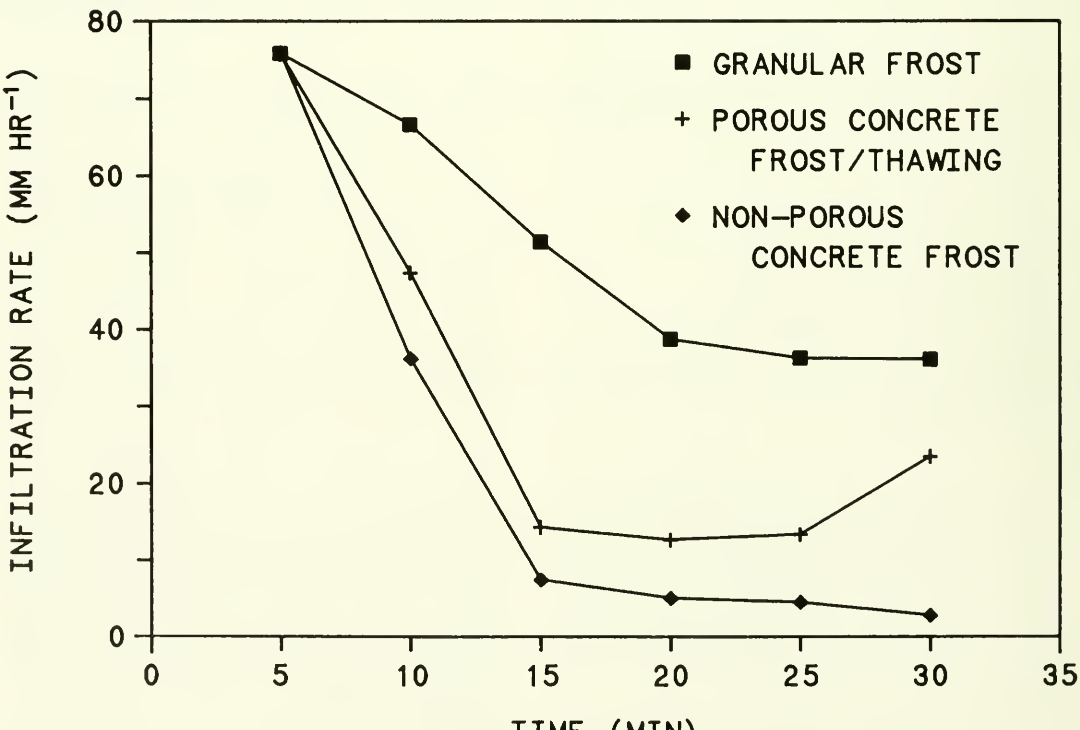

Fig. 3. Infiltration rates in January for dune interspace soils classified as having granular frost, porous concrete frost that was thawing during the rainfall event, and nonporous concrete frost, Crystal Springs, Nevada.

structure. Trimble et al. (1958), in New Hampshire, reported infiltration rate of soils with granular frost to be higher than that of unfrozen soils. Haupt (1967) found, for the eastern slope of the Sierra Nevada, the infiltration rate of porous concrete frost to increase as the soil thawed. Trimble et al. (1958) and Stoeckeler and Weitzman (1960) found infiltration rates of nonporous concrete frost in northern Minnesota to be very low.

CONCLUSIONS

The infiltration rate of shrub coppice dune soils was greater than dune interspace soils under frozen and unfrozen conditions. Concrete frost located 50 mm below the surface had a pronounced effect on infiltration rates. Infiltration rates of soils with porous concrete frost increased as the soils thawed during the simulated rainfall, but soils with nonporous concrete frost allowed very little infiltration to occur. Both coppice dune and dune interspace soils classified as having granular frost had a higher infiltration rate than the same unfrozen soils in March. Due to different vegetation cover and surface soil characteristics, shrub coppice dune and dune interspace soils responded differently to soil freezing and thus imposed a spatial and temporal response to infiltration rate.

LITERATURE CITED

BLACKBURN, W. H. 1975. Factors influencing infiltration and sediment production of semi-arid rangelands in Nevada. Water Resources Research 11: 929–937.

BLACKBURN, W. H., R. O. MEEUWIG, AND C. M. SKAU. 1974. A mobile infiltrometer for use on rangeland. Journal of Range Management 27: 322–323.

GRAY, D. M., AND R. J. GRANGER. 1987. Frozen soil: the problem of snow melt infiltration. *In:* Y. S. Fok, ed., Proceedings, International Conference on Infiltration Development and Application, Water Resources Research Center, University of Hawaii, Honolulu.

HALE, C. E. 1951. Further observations on soil freezing in the Pacific Northwest. Pacific Northwest Forest and Range Experiment Station Research Note No. 74, Portland, Oregon.

HARRIS, A. R. 1972. Infiltration rate as affected by soil freezing under three cover types. Soil Science Society of America Proceedings 36: 489–492.

HAUPT, H. F. 1967. Infiltration, overland flow and soil movement on frozen and snow-covered plot. Water Resources Research 3: 145–161.

JOHNSON, C. W., AND N. E. GORDON. 1988. Runoff and erosion from rainfall simulator plots on sagebrush rangeland. Transactions of the American Society of Agricultural Engineers 31: 421–427.

KANE, D. L., AND J. STEIN. 1983. Water movement into frozen soils. Water Resources Research 19: 1547–1557.

KLOCK, G. O. 1972. Snow melt temperature influence on infiltration and soil water retention. Journal of Soil and Water Conservation 27: 12–14.

KUZICK, I. A., AND A. I. BEZMENOV. 1963. Infiltration of meltwater into frozen soil. Soviet Soil Science 6: 665–670.

LAWS, J. D. 1941. Measurements of the fall-velocity of water-drops and raindrops. Transactions of the American Geophysical Union 22: 709–721.

LEE, R. W., AND M. P. MOLNAU. 1982. Infiltration into frozen soils using simulated rainfall. Paper No. 82-2048, American Society of Agricultural Engineers, St. Joseph, Michigan.

PIKUL, J. L., JR., AND R. R. ALLMARAS. 1986. Physical and chemical properties of a Haploxeroll after 50 years of residue management. Soil Science Society of America Journal 50: 214–219.

SNEDECOR, G. W., AND W. G. COCHRAN. 1971. Statistical methods. Iowa State University Press, Ames.

STOECKELER, J. H., AND S. WEITZMAN. 1960. Infiltration rates in frozen soils in northern Minnesota. Soil Science Society of America Proceedings 24: 137–139.

STORY, H. C. 1955. Frozen soil and spring and winter floods. *In:* Yearbook of Agriculture 1955. U.S. Department of Agriculture, Washington, D.C.

SWANSON, S. R., AND J. C. BUCKHOUSE. 1984. Soil and nitrogen loss from Oregon lands occupied by three subspecies of big sagebrush. Journal of Range Management 37: 298–302.

THUROW, T. L., W. H. BLACKBURN, AND C. A. TAYLOR, JR. 1986. Hydrologic characteristics of vegetation types as affected by livestock grazing systems, Edwards Plateau, Texas. Journal of Range Management 39: 505–509.

TRIMBLE, G. R., R. S. SARTZ, AND R. S. PIERCE. 1958. How types of soil frost affect infiltration. Journal of Soil and Water Conservation 13: 81–82.

WILCOX, B. P., C. L. HANSON, J. R. WIGHT, AND W. H. BLACKBURN. 1989. Sagebrush rangeland hydrology and evaluation of the SPUR hydrology model. Water Resources Bulletin 25: 653–666.

WOOD, J. C., M. K. WOOD, AND J. M. TROMBLE. 1987. Important factors influencing water infiltration and sediment production on arid lands in New Mexico. Journal of Arid Environment 12: 111–118.

WOOD, M. K. 1987. Plot numbers required to determine infiltration rates and sediment production on rangelands in southcentral New Mexico. Journal of Range Management 40: 259–263.

WOOD, M. K., AND W. H. BLACKBURN. 1981. Grazing systems: their influence on infiltration rates in the rolling plains of Texas. Journal of Range Management 34: 331–335.

Zuzel, J. F., and J. L. Pikul, Jr. 1987. Infiltration into a seasonably frozen agricultural soil. Journal of Soil and Water Conservation 42: 447–450.

Zuzel, J. F., J. L. Pikul, Jr., and R. N. Greenwalt. 1986. Point probability distributions of frozen soil. Journal of Climate and Applied Meteorology 25: 1681–1686.

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